

# Dispersive contribution to CP violation in hyperon decays

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## Abstract

Within the standard model, CP-violating asymmetries  $A(\Lambda_-^0)$  and  $A(\Xi_-)$  have been estimated in short-distance calculations to occur at the level of a few times  $10^{-5}$ . We show here that in this model the dispersive contribution tends to give asymmetries of similar size.

A lot of interest is now directed towards understanding the origin of CP violation in particle physics [1]. Among various processes considered as promising areas of experimental study, the nonleptonic hyperon decays offer the possibility to observe CP violation in  $\Delta S = 1$  transitions. The upcoming E871 experiment is expected to reach sensitivity of  $10^{-4}$  for the sum of CP-violating asymmetries  $A(\Lambda_-^0)$  and  $A(\Xi_-)$  [2]. Estimates of these asymmetries within standard model yield values at a few times  $10^{-5}$  level [3, 4]. It has been stressed [3] that good understanding of the dominant CP-conserving part of nonleptonic hyperon decays as well as knowledge of strong interaction effects (and, in particular, of scattering phases) are indispensable if we are to draw meaningful conclusions from any observed signal of CP violation.

Recently an economic and successful model of the CP-conserving part of hyperon nonleptonic decays has been proposed [5]. The success of the model stems from allowing a substantial (relative to  $W$ -exchange) total penguin contribution in baryon-to-baryon weak transitions (see Fig.1). In agreement with general requirements of chiral and weakly broken  $SU(3)$  symmetries the contributions from diagrams with weak Hamiltonian acting in the meson leg were assumed non-dominant. Without introducing *any* additional parameters the model of ref.[5] generates a relation between the values of the  $f/d$  ratios for S- and P- waves, which agrees with experiment very well. Thus, it is plausible that the origin of the difference in the values of the  $f/d$  ratios for the two waves has been identified. As a by-product the approach fixes then the size of (the real part of) the total penguin contributions in the S- and P-waves.

Short-distance estimates of the CP-conserving part of penguin contribution in hyperon decays yield values that fall short of the data by a factor of at least 5 [6]. A similar factor of 5 is needed in kaon decays as well. Arguments have been presented that such factors presumably originate from long-range hadron-level effects [7, 8, 9].

If hadron-level effects are indeed that important, then for a reliable estimate of the CP-violating penguin contribution one has to consider both hadron-level (dispersive) and short-distance effects. However, the estimates of CP violation in hyperon decays carried out so far are based on short-distance calculations only [3, 10, 11].

In order to estimate the dispersive effects we assume in the following that the total penguin contribution to nonleptonic hyperon decays is dominated by hadron-loop effects. If these effects are smaller the numbers calculated below should be scaled down appropriately.

The data fix the reduced  $SU(6)$  matrix elements corresponding to  $W$ -exchange and penguin diagrams  $((b1) + (b2))$  and  $(c1) + (c2)$  of Fig.1) to be (in units of  $10^{-7}$ , see ref.[5])

(1) for S-waves:

$$\begin{aligned} b_S &= -5 \\ c_S &= 12 \end{aligned} \tag{1}$$

with  $(f/d)_S = -1 + 2c_S/(3b_S) = -2.6$

2) for P-waves:

$$\begin{aligned} b_P &= -132 \\ c_P &= 158 \end{aligned} \tag{2}$$

with  $(f/d)_P = -1 + 2c_P/(3b_P) = -1.8$ .

The obtained description of  $\Lambda_-^0$  and  $\Xi_-^-$  decays is compared with experiment in Table 1 (for a more complete account see ref.[5]). It is known that the  $F/D$  ratio describing the  $SU(3)$  structure of strong couplings relevant in the expressions for the P-wave amplitudes is around 0.57 which is slightly different from its  $SU(6)$  value of

2/3 implicitly assumed in Eq.(2). Description of P-wave amplitudes for  $F/D = 0.57$  is given in Table 1 as well.

Table 1. Full amplitudes and penguin contributions in CP-conserving amplitudes of nonleptonic hyperon decays.

	wave	SU(3) expression	penguin	total	experiment
$\Lambda_-^0$	S	$-\frac{1}{2\sqrt{6}}b_S + \frac{1}{2\sqrt{6}}c_S$	2.45	3.47	3.23
	P (F/D)				
	2/3	$\frac{1}{6\sqrt{6}}b_P + \frac{1}{2\sqrt{6}}c_P$	32.3	23.3	22.1
	0.57		29.2	17.6	
$\Xi_-^-$	S	$\frac{1}{\sqrt{6}}b_S - \frac{1}{2\sqrt{6}}c_S$	-2.45	-4.49	-4.50
	P (F/D)				
	2/3	$-\frac{1}{3\sqrt{6}}b_P - \frac{1}{6\sqrt{6}}c_P$	-10.8	7.2	16.6
	0.57		-7.7	15.5	

The hadron-level penguin contribution arises from that part of hadronic loops which - when viewed at the quark level - generates quark loops with  $q = u, c$ , and  $t$  (Fig.2). Its real part - of interest to us - may be estimated through dispersion relations. Contribution from hadronic states involving  $t$  quarks may be safely neglected: the relevant thresholds are very remote. On the other hand, dispersive effects which correspond to  $u$  and  $c$  quark loops have to be considered. Although we will neglect direct contribution from the top states, the existence of  $t$  quark is felt in the  $u, c$  sector as a deviation from equality of  $V_{ud}^* V_{us}$  and  $-V_{cd}^* V_{cs}$ :

$$V_{cd}^* V_{cs} = -V_{ud}^* V_{us} - V_{td}^* V_{ts} \quad (3)$$

Thus, the sum of contributions from intermediate hadron states corresponding to

quark loops is

$$\begin{aligned} V_{ud}^* V_{us} L_H(u) + V_{cd}^* V_{cs} L_H(c) + V_{td}^* V_{ts} L_H(t) &\approx \\ &\approx V_{ud}^* V_{us} (L_H(u) - L_H(c)) - V_{td}^* V_{ts} L_H(c) \end{aligned} \quad (4)$$

where dependence on KM factors has been explicitly factored out of hadron-level-induced loop contribution  $L_H(q)$  of quark  $q$ . The second term on the r.h.s. of Eq.(4) induces CP violation. The size of the CP-violating term is governed by

$$\text{Im } \tau \equiv \text{Im} \frac{-V_{td}^* V_{ts}}{V_{ud}^* V_{us}} = A^2 \lambda^4 \eta \leq 10^{-3} \quad (5)$$

(using  $\lambda = 0.22$ ,  $A = 0.9 \pm 0.1$ , and  $\eta \leq 0.4 \pm 0.2$ ). Large mass of the  $c$  quark produces an additional suppression factor  $s_c$ , so that in fact the scale of CP violating amplitudes relative to the CP-conserving one is set by

$$\text{Im } \tau s_c \equiv \text{Im } \tau L_H(c) / (L_H(u) - L_H(c)) \quad (6)$$

To estimate the ratio of dispersive factors let us note that the long-range penguin contribution originates from weak transitions that occur within hadrons from intermediate meson+baryon virtual states. Loop factors  $L_H(q)$  are proportional to the probability of finding such a virtual state in a physical baryon and - with  $SU(4)$  symmetric couplings - they are inversely proportional to the squares of energy denominators. Thus,

$$L_H(c)/L_H(u) = [(E_{M_u} + E_{B_u} - E)/(E_{M_c} + E_{B_c} - E)]^2 \quad (7)$$

where  $E$  is total baryon energy, and  $E_{M_q}$ ,  $E_{B_q}$  are energies of the intermediate meson and baryon containing quark  $q$ . In a dispersive calculation the dominant contributions to dispersive integrals arise when intermediate meson (baryon) momenta  $k$  are in the range of  $k^2 \approx 0.6 - 1.2 \text{ GeV}^2$ . Indeed, the numerator in the integrand of the dispersion relation has a form of roughly

$$k^3 \exp(-(k/k_{cutoff})^2) \quad (8)$$

where the first factor comes from phase-space and the p-wave character of strong virtual decays, and the second factor arises from hadronic formfactors and provides the cutoff. In realistically sized hadrons  $k_{cutoff} \approx 0.7 \text{ GeV}$  [12], whence the above range of  $k^2$ . One estimates then that  $L_H(c)/L_H(u) \approx 0.1 - 0.2$ . In conclusion, dispersive calculations give  $s_c \approx 10 - 20\%$ . Calculation of CP asymmetries is now straightforward. Normalizing the penguin contribution to the full amplitude according to Table 1 one obtains the following weak phases

$$\begin{aligned}
\phi_S(\Lambda_-^0) &= +0.7 s_c \text{Im } \tau \\
\phi_P(\Lambda_-^0) &\approx +1.35 s_c \text{Im } \tau \\
\phi_S(\Xi_-^-) &= +0.54 s_c \text{Im } \tau \\
\phi_P(\Xi_-^-) &\approx -0.55 s_c \text{Im } \tau
\end{aligned} \tag{9}$$

The CP-violating asymmetries are then calculated from [3]

$$A = -\tan(\delta_P - \delta_S) \sin(\phi_P - \phi_S) \tag{10}$$

where  $\delta_{P,S}$  are phase shifts due to final-state strong interactions. With  $\text{Im } \tau \approx 10^{-3}$  and using  $\delta_P(\Lambda_-^0) = -1.1^\circ$ ,  $\delta_S(\Lambda_-^0) = +6.0^\circ$ ,  $\delta_P(\Xi_-^-) = -2.7^\circ$ , and  $\delta_S(\Xi_-^-) = -18.7^\circ$  from ref.[13] one gets

$$\begin{aligned}
A(\Lambda_-^0) &= 0.081 s_c \text{Im } \tau \approx (0.8 - 1.6) \cdot 10^{-5} \\
A(\Xi_-^-) &= 0.31 s_c \text{Im } \tau \approx (3 - 6) \cdot 10^{-5}
\end{aligned} \tag{11}$$

Thus, dispersive effects tend to give

$$A(\Lambda_-^0) + A(\Xi_-^-) = (3.8 - 7.6) \cdot 10^{-5} \tag{12}$$

i.e. a number at the same "a few times  $10^{-5}$  level" as the short-distance estimates. If for the  $\Xi_-^-$  decays one uses smaller strong rescattering phases (as calculated recently) the  $A(\Xi_-^-)$  asymmetry is scaled down accordingly.

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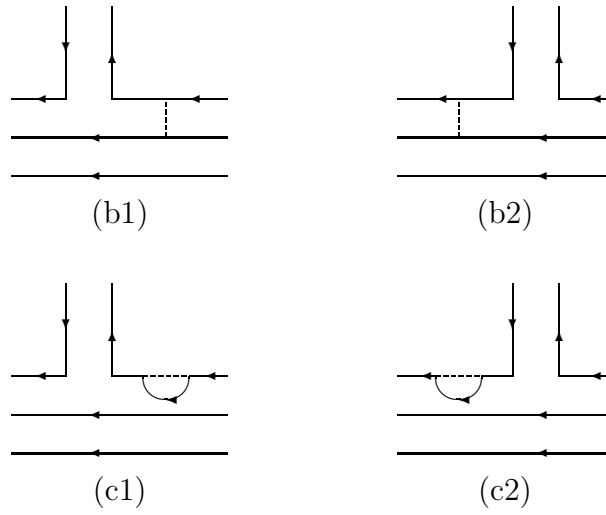


Fig.1. Quark diagrams for weak decays

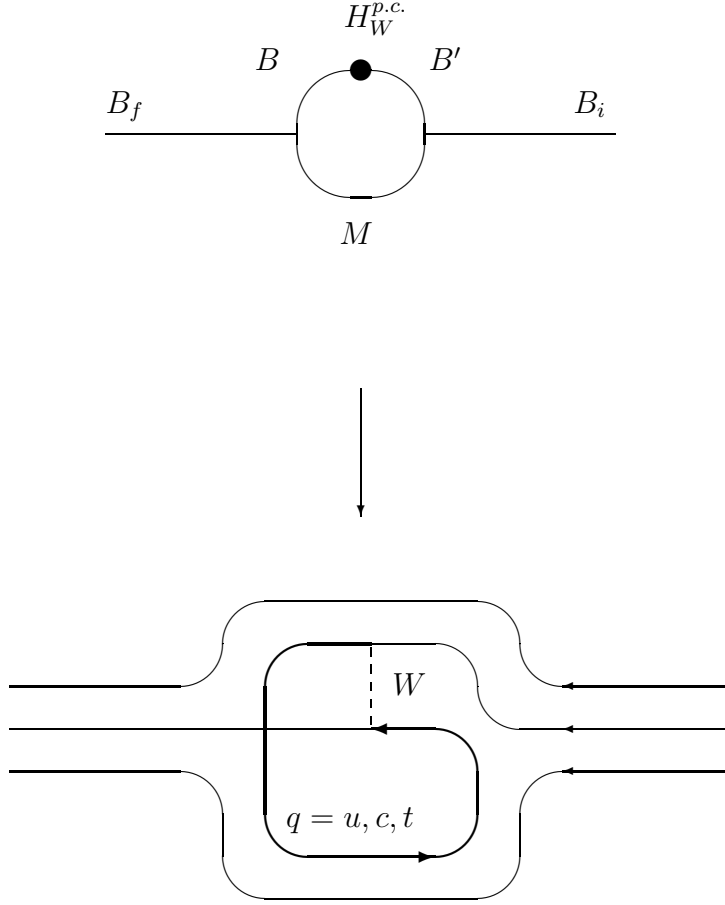


Fig.2. Example of quark-loop generation from a hadron-level loop diagram for the baryon-to-baryon matrix element of the parity conserving part of the weak Hamiltonian.